A NANOSECOND LIGHT-PULSE GENERATOR WITH EXTERNAL SYNCHRONIZATIONS

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A NANOSECOND LIGHT-PULSE GENERATOR WITH EXTERNAL SYNCHRONIZATION

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A generator of light pulses of ~ 1 nsec is described.　　　　/97*
External synchronization accuracy is better than 0.3 nsec;
amplitude stability is no worse than 5%; service life is
not less than 500 hr. at a frequency of 2.5 kHz. The tech-
nique of manufacturing the discharger is described. The
relationship is given between pulse length, interelectrode
distance, and gas pressure. The influence of the quality
of the electrode surface, frequency of pulse sequence and
overvoltage on synchronization accuracy is examined.

Fast electronic circuits which use photomultipliers are conveniently ad-
justed by means of light generators which make it possible to simulate the
striking of particles on to scintillation counters and to check the whole elec-
tronic circuit. The following basic demands are made on generators of this
type: duration of light pulse ~ 1 nsec, external triggering with an accuracy of
better than 1 nsec, quantity of light in the pulse comparable to the photopeak
in a crystal of NaJ(Tl) irradiated by γ-quanta of Cs^{137} (in the following, this
amount of light is called "standard"), amplitude fluctuation <10%, amplitude
stability in time no worse than 10%. Because of the lack of suitable light
generators, equipment must often be adjusted by means of accelerators.

The literature describes several methods of generating nanosecond light
pulses. Good external synchronization is a property of generators based on
semiconductors (Refs. 1, 2) and corona dischargers (Refs. 3, 4); their draw-
back is the weak light burst. In (Refs. 5 and 6) a special discharger is
broken down by means of a thyratron; synchronization accuracy (Ref. 5) is sev-
eral nanoseconds. Dischargers in the simple wiring diagram of (Refs. 7 and 8)
have no external synchronization. (Ref. 9) uses thyratrons and gas stabilizers
as light sources; pulse rise time is 3 nsec and pulse duration, several tens of
nanoseconds. Generators based on mercury relays (Refs. 10 and 11) have no
external synchronization. Moreover, amplitude stability of the generator in
(Ref. 11) is $\sim 15\%$. The present work has investigated the feasibility of
creating nanosecond light-pulse generators based on a special discharger.

1. Pulse Length

Structurally, the generator has the form of a coaxial line whose central
conductor is the discharger electrodes; wave impedance of the line is 75 ohm.
Apertures have been made in the casing of the line for illuminating the

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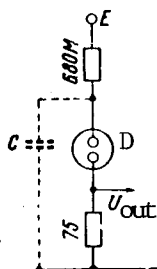* Numbers in the margin indicate pagination in the original foreign text.

$680M$

C

D

U_{out}

75

Figure 1

Wiring Circuit of Discharger D.
C -- Distributed Capacitance of
∿3 pf.

photomultipliers. Distance from dis-
charger to photocathode is 15 cm. Polar-
ized light-filters are employed to regu-
late the amount of light falling on the
photomultipliers. The discharger is
made up of two cylindrical electrodes,
3.5 mm in diameter, situated within a
hermetically sealed housing. In the
first version, the discharger housing
was made of plexiglass with vacuum
rubber used for sealing. The discharger
was filled with air. Later on, glass   /98
dischargers were used.

Figure 1 shows the simplest wiring cir-
cuit of a discharger. When the voltage
on the discharger reaches the critical

value E_{br}, there is a spark breakdown. Duration of the light pulse depends on
duration of the electric impulse and gas de-excitation time. Estimates based
on the width of the spectral lines show that, during spark breakdown in gas at
atmospheric pressure, de-excitation time is considerably less than 1 nsec.
Therefore, in order to obtain a short light pulse, it suffices to have a short
electric pulse. Duration of electric pulse U_{out} was measured on an ISO-1 os-
cillograph with a chracteristic pulse rise time of 1.2 nsec on the plates.
Table 1 gives the dependence of electrical pulse duration on distance between
electrodes.

TABLE 1

DEPENDENCE OF ELECTRIC PULSE DURATION AT HALF-HEIGHT
ON GAP (AIR 1 atm)

Gap, mm	E_{br}, kv	Duration of U_{out}, nsec
0.1	1.0	∿1
0.2	1.6	∿1
0.4	2.4	∿1
0.6	3.2	∿1
0.8	3.9	3

It is evident from the tabular data that at a gap of < 0.6 mm, light
pulse duration should not exceed 1 nsec. In the following, a gap of 0.25 to
0.5 mm was used. Modern industrial photomultipliers do not permit measurement
of a light pulse of ∿1 nsec. We employed a FEU-36 photomultiplier. The best
specimen of a photomultiplier under specifically selected operating conditions
gave a rise time of 2 nsec and a duration at the base of 6 nsec (at a height
of 0.1 of amplitude value). Noise pulses from the photomultiplier have the

same shape.

Table 2 gives the values of electrical and light pulse duration at lower gas pressures. It is evident that at pressures of > 150 torr, gas de-excitation time sharply decreases and becomes less than the resolving time of the measuring system.

TABLE 2

DEPENDENCE OF DURATION OF ELECTRICAL AND LIGHT PULSES
ON PRESSURE (AIR, GAP 0.45 mm)

Pressure, torr	E_{br}, v	Electrical Pulse		Pulse from Photomultiplier FEU-36	
		Rise time, nsec	Duration at half-height, nsec	Rise time, nsec	Decay time, nsec
15	< 600	12	12	20	35
55	700	5	8	11	20
90	850	4	5	6	16
150	1000	2	3	2.5	4
250	1550	∿1.5	2	2	4

2. Amplitude Resolution and Lifetime

The amplitude characteristics of the light generator were studied by means of a FEU-29 photomultiplier. The amount of light falling on the photocathode without filters is ∿10 times more than standard. When the amplitude spectra were recorded, the amount of light was chosen equal to standard by means of filters. Amplitude resolution, as well as lifetime, depends on electrode shape and quality of electrode surface. Several forms of the electrodes were tested. The best shape proved to be that of a flattened sphere -- almost flat in the center with rounded edges. The surface was finished with fine emery cloth. Polishing gave no better results.

To construct the generator it was necessary to choose electrodes having a long service life. Electrodes of different metals were tested for lifetime under identical conditions. The results were: brass -- 2.5 hr., Armco iron -- 6 hr., bismuth -- 17 hr., molybdenum -- > 30 hr. Frequency was maintained at ∿ 100 Hz; the discharger was filled with air at atmospheric pressure; filling with pure nitrogen resulted in no changes.

In subsequent work only molybdenum electrodes were employed. The average /99 decrease in light pulse amplitude in several dischargers was 10% after 50 hr of operation at 100 Hz. During that time, frequency increased by ∿ 20%. Amplitude resolution (relative line width at half-height) changed differently in time in various dischargers, and amounted to 7 to 15% after 50 hr. of operation.

3. Externally-Triggered Generator

During operation of the discharger, a change occurred in the electrode surface and led to a change in the breakdown voltage E_{br}. This provoked a change in light pulse amplitude. The discharger wiring circuit shown in Figure 2 was tested for stabilizing light pulse amplitude. Distributed capacitances C_1 and C_2 were charged to voltages E_1 and E_2, respectively. When a triggering pulse was delivered to the thyratron, capacitance C_2 discharged, and overvoltage $K_{pulse} = E_1/E_{br}$ appeared on the discharger. Voltage values and time constants of the circuits were selected from the conditions: $(E_1 - E_2) <$ $< E_{br} < E_1$, $R_1C_1 \approx R_2C_2 < f^{-1}$, where f is the triggering frequency of the thyratron. Under these operating conditions, capacitance C_1 is always charged to the same voltage before breakdown. The difference from the wiring circuit in (Ref. 5) lies in the fact that constant voltage $(E_1 - E_2)$ is maintained on the discharger before breakdown. This voltage creates a certain current through the discharger before breakdown, and this results in decrease in breakdown delay time and stabilization of light pulse amplitude.
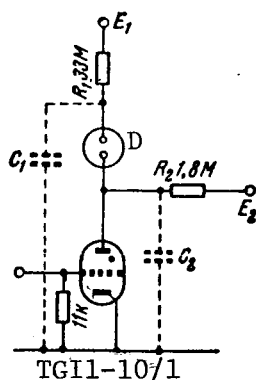

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Figure 2

Wiring Circuit for Discharger D.
C_1 and C_2 -- Distributed Capacitances.

The wiring circuit in Figure 2 chiefly used dischargers with electrodes welded into a glass housing. The principal difficulties encountered in manufacturing dischargers of this type involve the vaporization of molybdenum onto the discharger walls during heating, so that the leakage resistance between the electrodes becomes small. The following technique for manufacturing the discharger was developed.* The molybdenum electrodes (3.5 mm in diameter, 15 mm long) are first welded into glass sleeves, and then the sleeves are welded to the tube (Figure 3); the shape of the discharger makes it possible to carry out this operation without heating the electrodes. Gap size is 0.25 to 0.4 mm. The discharger is evacuated by a fore pump and filled with hydrogen to a pressure of 150 torr. Discharger breakdown voltage is 500 to 800 v; interelectrode leakage resistance is > 100 gigohm (at 100 v). For certain measurements, the electrodes were electrochemically cleaned of oxide (a current of 0.5 amp is passed for 30 sec through a 30% aqueous solution of potassium alkali; the electrode serves as the anode). This makes the electrode surface brilliant.

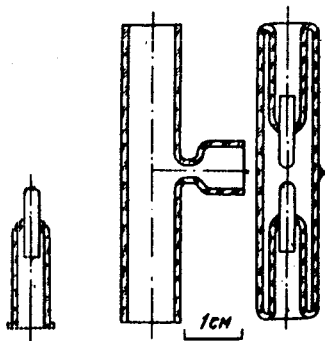* S. M. Zakharov participated in working out the technique.

Figure 3

Glass Discharger

Dischargers with cleaned electrodes of spherical and flattened form work equally well when wired in a thyratron circuit. For engineering considerations, electrodes of spherical shape were used. The effect of surface condition on synchronization accuracy is examined below.

Light pulse amplitude does not depend on voltage E_2 and is proportional to $C_1E_1^2$. Amplitude resolution is 6 to 10%. Pulse duration with the FEU-36 photomultiplier is the same as in the wiring diagram in Figure 1. The results of testing the stability of the light pulse amplitude are as follows: In 10 hours of operation, maximum instability does not exceed $\pm 2\%$; in 300 hours, it is no more than $\pm 5\%$. The generator operated at a frequency of 2.5 kHz; $E_1 =$ = 1.5 kv, $E_2 = 1.2$ kv, $E_{br} = 500$ v.

4. Accurate External Synchronization

Accuracy of external light-pulse synchronization in the circuit in Figure 2 depends, first, on accuracy of thyratron synchronization and, second, on accuracy of discharger synchronization with respect to the thyratron. The dependence of delay in thyratron firing on triggering-pulse amplitude, filament voltage, and high voltage was specially measured. When filament voltage is changed by 2%, or triggering pulse amplitude is changed by 3%, the delay changes by 1 nsec. Changing the high voltage by 20% varies the delay by 0.5 nsec. The filament was fed from a VS-13 rectifier. A GKI-5 generator was used for triggering; triggering-pulse amplitude was 250 v. Discharge time of capacitance C_2 was 5 nsec, and delay time was 30 to 90 nsec (the spread pertains to different thyratron specimens). Despite such great delays, synchronization accuracy is better than 0.3 nsec.

Discharger synchronization accuracy depends on the state of the electrode surface, overvoltage $K_{pulse} = E_1/E_{br}$, constant voltage on the discharger before breakdown $K_c = (E_1 - E_2)/E_{br}$, and on the time interval between pulses. Measurements of synchronization accuracy with cleaned electrodes and with electrodes covered with an oxide film were conducted. Accuracy of synchronization with uncleaned electrodes is considerably better than with cleaned. This involves the fact that, if the electrodes are covered with an insulating film, the preceding breakdown substantially reduces the statistical breakdown delay time. (Ref. 12) gives an explanation of this effect. In the following, we employed only dischargers with oxidized electrodes.

The thyratron was triggered by two successive impulses to measure the dependence of synchronization accuracy on the time interval between breakdowns,
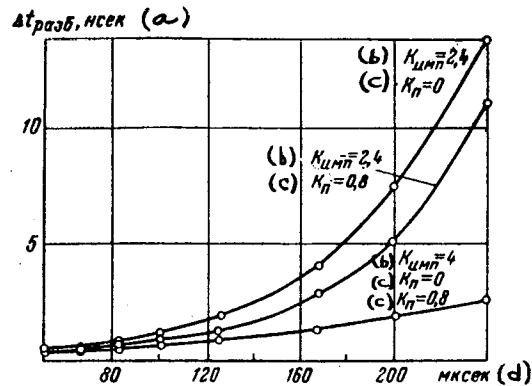
Figure 4

Dependence of Synchronization Accuracy Δt_{spread} on
Time Between Pulses

$K_{pulse} = E_1/E_{br}$, $K_c = (E_1 - E_2)/E_{br}$. Oxidized electrodes.

(a) - Δt_{spread}, nsec; (b) - $K_{pulse} = $; (c) - $K_c = $;
(d) - microsec.

and synchronization accuracy of the second pulse was observed on an oscillo-
graph at different delays with respect to the first. Figure 4 gives the results
for various values of K_{pulse} and K_c. It is apparent that synchronization with
an accuracy of $\lesssim$ 1 nsec requires that the delay not exceed 150 microsec. This
may also be achieved by the frequency of pulse repetitiion or operating condi-
tions with characteristic breakdowns.

The concept of generator operation in a regime with characteristic break-
downs consists of the following. If voltages E_1 and E_2 are so selected that
$E_1 - E_2 > E_{br}$, then in the interval between the main pulses, characteristic
breakdowns will occur. These break-
downs prepare the discharger for the
arrival of the fundamental pulse. Fig-
ure 5 shows an oscillogram of the opera-
tion of the generator in a regime with
characteristic breakdowns. In this re-
gime, it is easy to obtain good synchron-
ization of the fundamental pulse, but /101
hard to stabilize amplitude. This is
associated with the change in breakdown
voltage leading to a change in the time
interval before the preceding charac-
teristic breakdown, with the result that
capacitance C_1 before the breakdown
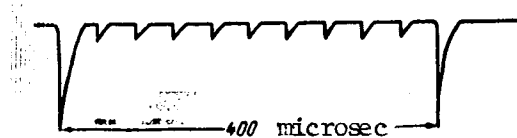proves to be charged to different

Figure 5

Operation of Generator in Regime With
Characteristic Breakdowns. Oscillo-
gram of Pulses from Photomultiplier:
Large-amplitude pulses are the funda-
mental pulses; low-amplitude pulses
are the characteristic breakdowns.

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voltages. In this regime, we measured the stability of external synchronization in time by means of a circuit of the coincidence type (Ref. 13). To one input we fed pulses from a FEU-36 photomultiplier; and to the other, pulses from a GKI-5 generator. The resolving time with 50% recording efficiency was $2\tau = 1.5$ nsec. After 100 hr. of operation, the change in time delay was ± 0.2 nsec. The generator operated at a frequency of 2.5 kHz; $E_1 = 2$ kv, $E_2 = 1.2$ kv, $E_{br} = 500$ v. The number of characteristic breakdowns between fundamental pulses varied from 10 to 11. Fundamental-pulse amplitude stability in this time was $\pm 15\%$.

At times it is more convenient to utilize an electron tube instead of a thyratron; the 6V2P was tested for this purpose. In its usual state the tube is closed. Pulses 100 v in amplitude with a rise time of 5 nsec are delivered to the control grid. Discharge time of capacitance C_2 is 2 nsec. This circuit operated for a long time at a frequency of 10 kHz. Synchronization accuracy was better than 0.3 nsec; amplitude instability in 100 hr. was $\pm 2\%$. The operating regime was: $E_1 = 2550$ v, $E_2 = 2050$ v, $E_{br} = 640$ v.

In conclusion, I thank A. G. Khabakhpashev and V. A. Sidorov for discussion of the work, and S. G. Roshchin, V. I. Obodzinskiy, V. A. Yakovlev, and V. A. Tseluykin for help in the work.

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Note during proof-reading. Light pulse duration at half-height in a regime with a 6V2P tube measured by the single-electron fluctuation method (Y. Koehlin and A. Raviart. Nuclear Instruments and Methods, 29, 45) is 2 nsec.